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DTIC ACCESSION NUMBER: AD A101556

LEVEL: 1

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ARINC Research Corp.
Annapolis, Md.
Report No. 1326-01-12-2193
Final Rpt. April, 80
FAA-EM-80-6

DOCUMENT IDENTIFICATION

Contract DOT-FA76WA-3788

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DEVELOPMENT OF ATC TRANSPONDER RELIABILITY IN AIR CARRIER AND GENERAL AVIATION AIRCRAFT

FINAL REPORT

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APRIL 1980

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D.C. 20591
under Contract DOT-FA76WA-3788

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-EM-80-6		

4. Title and Subtitle Development of ATC Transponder Reliability in Air Carrier and General Aviation Aircraft	5. Report Date April 1980 6. Performing Organization Code
7. Author(s) S. Kowalski, K. Peter	8. Performing Organization Report No. 1326-01-12-2193
9. Performing Organization Name and Address ARINC Research Corporation 2551 Riva Road Annapolis, Maryland 21401	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-FA76WA-3788
12. Sponsoring Agency Name and Address U. S. Department of Transportation Federal Aviation Administration Office of Systems Engineering Management Washington, D.C. 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report presents the results of a study to determine the reliability of the ATC transponder system in air carrier aircraft and low-performance general aviation aircraft. Data presented on air carrier class of transponders are based on historical records of the air carriers for equipment removal and repair activity. Data presented on the general aviation class of transponders are based on warranty action information furnished by four of the leading avionics manufacturers producing transponders.

17. Key Words	18. Distribution Statement

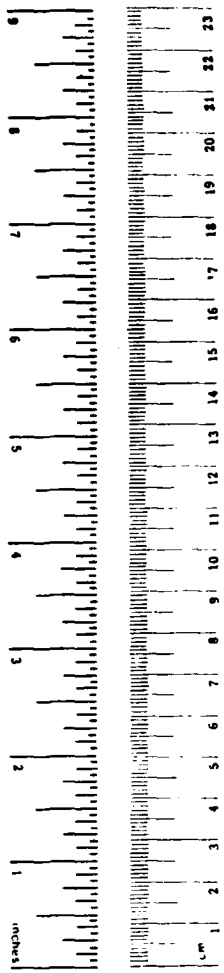
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	20	

Form DOT F 1700.7 (8-72)

METRIC CONVERSION FACTORS

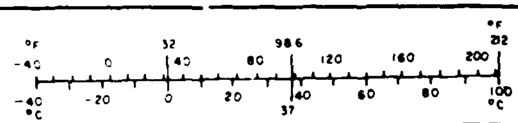
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENT

While collecting data during this study to determine the reliability of ATC transponders, ARINC Research Corporation received enthusiastic cooperation from selected air carriers and general aviation avionics manufacturers. The Federal Aviation Administration provided the overall guidance for the study, while the maintenance organizations supplied the necessary transponder failure data. We wish to acknowledge the support we received from the following corporations and key individuals within the corporations who actively participated in this study and without whose assistance we could not have provided the historical data to validate this study:

U.S. Air Carrier Maintenance Facilities

American Airlines	Frank Chandler
Continental Airlines	E. F. Huettner
Delta Air Lines	Robert M. Cook
Eastern Airlines	Thomas H. Barton
Pacific Southwest Airlines	Brad Vandenburgh
Piedmont Airlines	K. D. Oakley
Trans World Airlines	W. O. Blake
United Airlines	F. L. Mohr

General Aviation Avionics Manufacturers

Bendix Corporation	W. Baumiller
King Radio Corporation	W. M. Hansford, Jr.
Narco Avionics	H. Older
Rockwell International/ Collins	L. Beckett

SUMMARY

The air traffic control (ATC) transponder is a vital part of the effective operation of the National Airspace System. As part of the Federal Aviation Administration program to maintain a high degree of flight safety, the Office of Systems Engineering Management is examining the effectiveness of the secondary surveillance radar system and has tasked ARINC Research Corporation to develop reliability data on ATC transponders used on air-carrier and low-performance general aviation aircraft.

The data presented in this study report the number of removals and repairs of transponders by eight commercial air carriers during a 12-month period and warranty actions performed by four leading general aviation avionics manufacturers during a typical 12-month warranty period.

Transponders operated by air carriers averaged 2,405 hours mean time between unit removals (MTBUR), with the data representing the average rate for more than 65 percent of the aircraft in the air-carrier inventory. Because the majority of air carriers normally provide dual flight-critical avionics, the probability of one or more system failures in flight by the combined fleet of air-carrier aircraft with dual transponder systems during 12 months of operation is 36 percent or less.

Transponders used by the low-performance general aviation aircraft average a mean time between failures (MTBF) of 1,945 hours. Because of the large population of aircraft in this community (more than 180,000 aircraft active in 1979) and their typically short-range activity, the number of aircraft visible to surveillance radar that would probably generate at least one failure per day was calculated. The results show that if the average flight time of the aircraft is two hours, there is a 95 percent probability that one failure will occur per day among 2,913 aircraft in any volume of airspace.

CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Air Traffic Control (ATC) system developed and operated by the Federal Aviation Administration (FAA) to provide safety in flight to all users of the National Airspace System (NAS) is heavily dependent on information provided by airborne transponders replying to the secondary surveillance radar interrogations. All certified air carriers and the majority of general aviation aircraft are equipped with ATC transponders that, when working, provide air traffic controllers with slant range and bearing information relative to the ground interrogators and in many cases the aircraft altitude.

As part of the FAA program to maintain a high degree of flight safety, the Office of Systems Engineering Management (OSEM) is examining the effectiveness of the secondary surveillance radar system and has tasked ARINC Research Corporation, under Contract DOT-FA76WA-3788, to develop reliability data on ATC transponders used on air-carrier and low-performance general aviation aircraft.

1.2 STUDY APPROACH

To obtain representative reliability data for the two communities of users, different approaches were considered necessary to optimize confidence variations with availability of historical data.

The certified air carriers maintain detailed data regarding equipment removal and repair and document the data for monthly, quarterly, and annual review. Several air carriers provided data on removal rates, confirmed failure reports, fleet flight hours, and complement of avionics by aircraft type. The data collection effort was limited to data for the past 12 months to facilitate data reduction and represent current equipment rather than previous equipment whose failure rate may no longer affect the ATC.

The low-performance general aviation aircraft community does not maintain accurate records at a centrally available facility. Surveying a sample of the operators was considered but rejected because the contract schedule would not permit a sample large enough to be representative of the

total population. The manufacturers of ATC transponders, however, maintain accurate records of repairs performed at the manufacturing facility or an authorized field repair facility during the 12-month period of avionics warranty. Several manufacturers provided data on repairs during warranty for all transponders they manufacture that are believed to be still in use. These data were combined with general aviation activity data to develop the probable reliabilities of airborne ATC transponders.

1.3 REPORT ORGANIZATION

This report presents the results of an evaluation of data on ATC transponder reliabilities.

Chapter Two documents the data collection effort and presents the transponder reliabilities for each community of users.

Chapter Three evaluates the effect of transponder reliabilities on the ATC system.

Chapter Four summarizes the results of the evaluation.

CHAPTER TWO

DEVELOPMENT OF TRANSPONDER RELIABILITY DATA

The data presented in this chapter were collected from commercial air carriers and general aviation manufacturers and represent a weighted average of the data furnished by the participants in the study. The data have been reduced to two major categories of users, each representing a large population of aircraft: the commercial air carriers, and the low-performance single-engine and light twin-engine aircraft. This chapter presents the results of the investigation of ATC transponder reliabilities for each user category.

2.1 COMMERCIAL AIR CARRIERS

The eight U.S. air carriers contributing to this transponder reliability study represent almost 65 percent of the aircraft in the air-carrier inventory. Each contributing air carrier has its own maintenance facilities and maintains its own avionics. Data are maintained on all removals and repairs of avionics and reviewed at periodic intervals. Since the intervals vary among the air carriers, quarterly and annual data were collected; these form the basis for the evaluation.

Data were collected by aircraft type, and in most cases both unscheduled removals from aircraft and confirmed failure information were available; however, only unscheduled removal data by total air-carrier fleet are considered in the analysis. The decision to consider removals, rather than failures, is predicated on the intent of the study to identify the availability of ATC transponder systems in the airspace rather than the reliability of the transponder itself. Transponders are removed after a pilot decides that the system is not operating and therefore not available to ATC. The ultimate cause of system failure is often traced to other factors, such as altimeter or control unit failures, but the circumstances nevertheless result in the unit's being shut down and removed, depriving ATC of the transponder capability.

All air carriers contributing information to this study follow the common practice of installing dual flight-critical avionics such as the ATC transponders. Although variations exist in the number of control units or antennas associated with the dual installation, depending on air carrier and aircraft type, none of the companies has recorded or can recall a failure of a dual system in flight during the past twelve months.

Table 2-1 presents the results of the investigation into ATC transponder availability in air-carrier aircraft. The annual operating hours shown represent the total number of hours during which the transponders were considered to be part of the ATC system. These hours are exactly twice the recorded flight hours of the aircraft (there are two systems for each aircraft) and are the basis for determining both the removal rate and failure rate. However, maintenance personnel at the air-carrier facilities reported that transponders are actually turned on between 50 and 100 percent longer because of pre-flight checkout, maintenance check-out in aircraft, and other activities that cause the aircraft to be powered but not in flight. In most of these cases the transponders are in the standby mode.

Table 2-1. ANNUAL ATC STATISTICS FOR AIR-CARRIER TRANSPONDERS

Equipment	Number of Aircraft	Annual Operating Hours	Number of Removals	Removal Rate (per 1,000 Hours)	MTBUR (Hours)	MTBF (Hours)
ATC Transponder	1,425	7,535,187	3,13[illegible]	0.4158	2,405	5,050
Control Panel	450	2,406,642	203	0.0844	11,855	16,695

Table 2-1 also presents the total number of unit removals during the 12-month period of interest and a removal rate as a function of operating hours per 1,000 hours of operation. All air carriers except Delta Air Lines provided 12-month statistics. Delta Air Lines provided six-month data, which were doubled to establish a uniform 12-month sample. The table also presents mean-time-between-failures (MTBF) data, which are the average confirmed failures of the units removed in relation to operating hours. However, these data are based on a smaller sample because not all of the air carriers provided these statistics. Comparing the MTBF data with the mean-time-between-unit-removals (MTBUR) data shows that the ratio of unit removal to unit failure is approximately 2:1. This corresponds to the observed ratio between removal rates and failure rates for only those air-carriers that provided both sets of data.

Table 2-1 also presents removal and failure data on ATC transponder control panels, although these data represent a smaller sample of the population as can be seen from the annual operating hours. Only three air carriers were requested to provide these data, resulting in limited information on which to draw any conclusions, but the data are considered indicative of the probable reliabilities of all the control units. Even if the control units should fail in flight, the failure would not cause a transponder failure other than possibly an inability to change the identification code.

Figure 2-1 presents the histogram of the distribution of transponder removals as a function of operating hours by each air carrier. The abscissa identifies the total number of units removed by the air carrier in the 12-month period while the ordinate shows the removal rate per 1,000 hours of operation. The corresponding number in parentheses is the MTBUR associated with each removal rate. The system average removal rate for all eight air carriers is plotted as a textured bar on the figure and shows that historically transponders are removed once every 2,405 hours of total transponder operation (1,200 hours of aircraft operating time). The effect on ATC operations of these removal rates is evaluated in the next chapter.

2.2 LOW-PERFORMANCE GENERAL AVIATION AIRCRAFT

The general aviation community represents the largest population of airspace users, in both number of aircraft registered and number of hours flown per year. According to FAA Aviation Forecasts, dated September 1979, the general aviation community in 1979 recorded 184,000 fixed-wing aircraft, which flew a total of 33.9 million hours. Since the majority of the aircraft are either individually owned or included in small fleets, statistical data on avionics maintenance is kept by either the very large number of owners or by over 500 authorized repair facilities dispersed throughout the United States. Collection of these data from a large enough portion of the repair facilities to establish an adequate sample would have been an overwhelming task, not feasible within the allowable schedule of the contractual effort. As an alternative technique to a survey of owners, several leading transponder manufacturers were requested to provide warranty action information for the 12-month period of unit warranty. Since all transponders under warranty are repaired either by the manufacturer or by authorized repair facilities with the manufacturer financially compensating the repair facility, good information is available on the number of warranty actions during a fixed time frame.

New transponders, when first introduced, usually exhibit certain design peculiarities, which are identified and corrected during the first year of operation. Reliability considerations are also carefully tracked by the manufacturers to minimize warranty costs. Data provided by the manufacturers show improvement in reliability as the transponder design matures and more units are manufactured. Although this study presents the probable reliability of transponders based on warranty action during a 12-month period, the data base for the evaluation includes, where available, total warranty actions since transponder introduction. Because the total warranty information used reflects various stages of transponder maturity, the reliability data are more representative of the systems as seen by ATC than reliability data that might be expected from new units recently manufactured. However, these data result in lower reliability than can be expected from currently manufactured transponders and will not agree with claims being made by the manufacturers for new avionics.

Since the intent of this study is to identify the availability of operational transponders to the ATC system, it was necessary to interpret certain warranty data to eliminate failures that occurred but were not

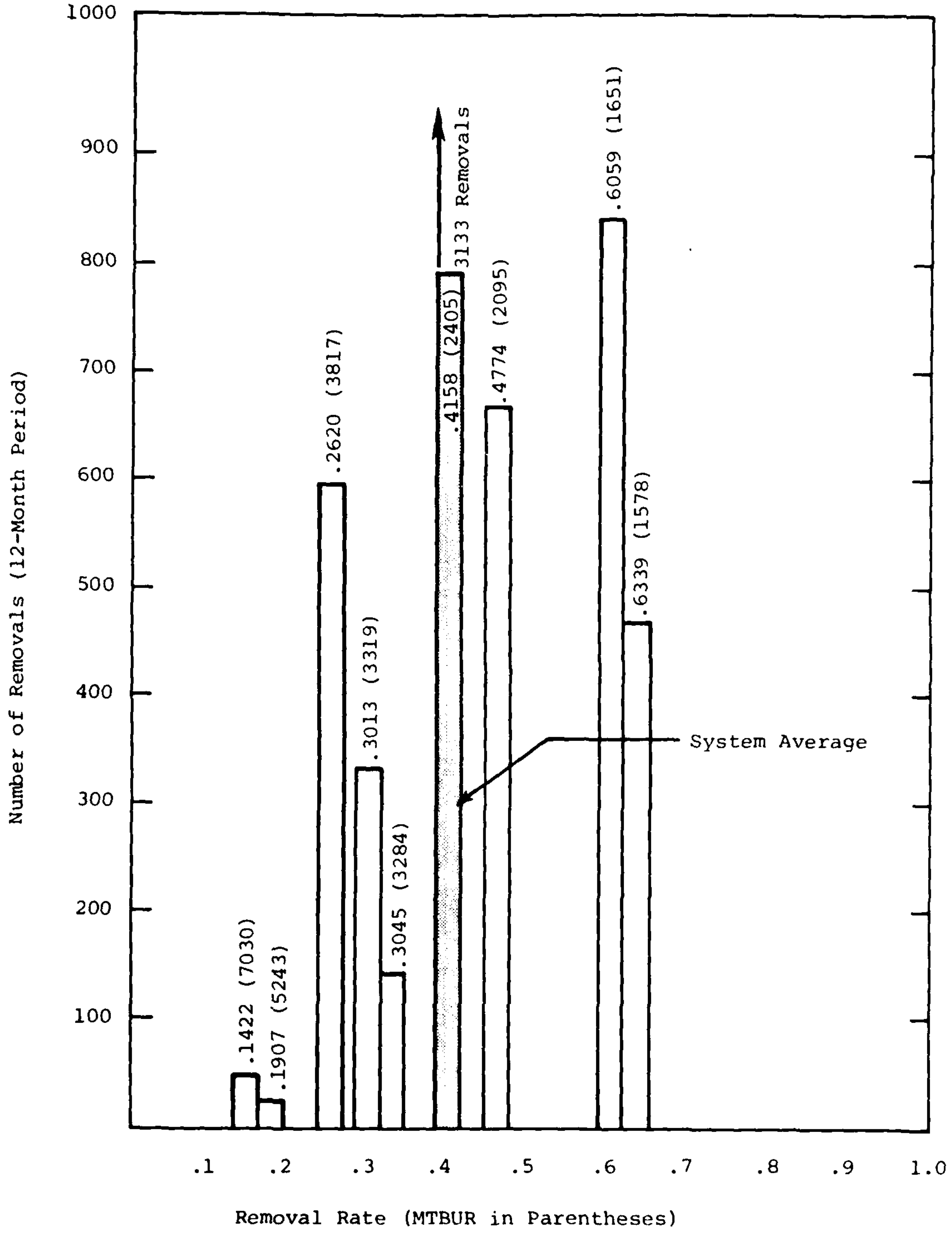


Figure 2-1. DISTRIBUTION OF TRANSPONDER REMOVALS AS A FUNCTION OF OPERATING HOURS BY AIR CARRIER

exposed to the ATC. These included failures detected during transponder installation and those of a mechanical nature not affecting transponder operation. Information furnished by the manufacturers indicates that the majority of warranty claims received during the first month of warranty represent failures detected during installation; as a result, the first month's statistics were eliminated from this study. On the basis of a subjective recommendation by the quality assurance personnel of the manufacturers, the remainder of warranty actions were reduced by 20 percent to allow for mechanical failures not affecting transponder electrical operation. The resultant number of warranty actions documented by the manufacturers forms the basis for evaluation during a 12-month period of operation in the NAS.

The four manufacturers consulted have produced and distributed 133,714 transponders of modern design. Ignoring catastrophic failures and normal replacement, the total number distributed can be considered as installed and operating in the NAS. In addition to those four manufacturers, at least four other manufacturers (ARC, EDO-AIRE, Genave, and Terra) produce transponders for low-performance general aviation aircraft. The quantity of transponders produced and distributed by these additional manufacturers was not investigated but should be sufficiently large to justify the assumption that the majority of general aviation aircraft are equipped with transponders.

Table 2-2 presents the expected reliability for the distributed transponders based on warranty action information. For 26,053 transponders in warranty during the 12-month period of interest, 3,252 warranty actions were recorded. On the basis of the average annual flight time of 194.2 hours for general aviation aircraft documented in Report No. FAA-MS-79-5,* the expected MTBF for this class of avionics is 1,945 hours. These data must be used with some degree of caution, since they are based on warranty actions performed on new transponders. The manufacturers are constantly attempting to improve avionics reliability through redesign and modifications. When a unit is returned for warranty action, it frequently is modified to include the latest reliability improvements. The modified unit then may have higher MTBF than is reflected in this evaluation. In addition, the maturity of design and production quantities must be considered. The majority of the units considered in the evaluation have been in production for many years, attaining the expected maturity improvement. However, a sizable number are of recent design and still subject to typical improvements during the course of quantity production. One manufacturer's records show a 250-percent reduction in warranty claims in five years of a transponder type production; that is probably typical of maturity improvements among the quality manufacturers.

*1977 General Aviation Activity and Avionics Survey, April 1979, Annual Summary Report.

Table 2-2. ANNUAL ATC RELIABILITY STATISTICS FOR GENERAL AVIATION TRANSPONDERS (BASED ON WARRANTY DATA)

Number of Transponders in Sample	Average Number of Units in Warranty	Number of Claims During Warranty	Transponder Repair Rate*	Transponder Availability to ATC as a Function of Annual Flight Hours (MTBF)
133,714	26,053	3,252	0.0998	1,945

*The repair rate is based on the assumption that 80 percent of warranty claims affect ATC operation.

CHAPTER THREE

EFFECT OF TRANSPONDER RELIABILITY ON THE ATC SYSTEM

Control of aircraft movement by ATC controllers is dependent on position information provided by transponder replies to the secondary surveillance interrogations of the ATCRBS system. Flight following and separation assurance are made possible through display of aircraft position to the controllers responsible for flight safety in their areas of coverage. The availability of transponder replies, therefore, is a critical feature of today's safe operation of the NAS. This chapter presents the evaluation of transponder availability based on the reliability data documented in Chapter Two. The information is presented for the air-carrier population, which is always under ATC control, and for the majority of the general aviation population, which may avail itself of ATC control but generally operates in air space where transponders are not mandatory.

3.1 AVAILABILITY OF TRANSPONDER REPLIES IN AIR-CARRIER POPULATION

The majority of the commercial air carriers in the United States follow the common practice of installing redundant flight-critical avionics. Since ATC transponders are mandatory for normal air-carrier flights, all aircraft associated with the air carriers contacted have two transponders, with one unit in operation and the second in standby. Failures are corrected at either the next destination after failure detection, or at the next destination having maintenance support. Generally, aircraft will not depart on an extended flight unless both transponders are operational. The effect of this operational philosophy is a reliable transponder system with a very high probability of successful flight without system failure. Following the recommended practice of MIL-HDBK-217B for predicting probability of mission success when one unit out of two must be working for success, the following formula can be used:

$$P_s = 2e^{-\lambda t} - e^{-2\lambda t} \qquad (3\text{-}1)$$

where

P_s = probability of mission success

λ = transponder failure rate

t = duration of mission in hours

Table 3-1 presents the probability of success for flights with average durations ranging from 1 to 10 hours. In order to provide a base for comparison, Table 3-1 also presents the probability of success if the aircraft is fitted with single transponder systems. The reliability equation for this configuration is:

$$P_s = e^{-\lambda t} \tag{3-2}$$

The expected probability of failure ($1 - P_S$) of a single transponder system for a flight of five hours duration, for example, is almost 1,000 times greater than expected from a redundant transponder system with one unit operational and one in standby.

Table 3-1. PROBABILITY OF MISSION SUCCESS AS A FUNCTION OF MISSION DURATION - AIR CARRIER COMMUNITY

Duration of Flight (Hours)	Probability of Success - Redundant System	Probability of Success - Single System
1	0.999999827	0.999584286
2	0.999999309	0.999168746
3	0.999998446	0.998753378
4	0.999997239	0.998338182
5	0.999995687	0.997923160
6	0.999993792	0.997508309
7	0.999991553	0.997093632
8	0.999988972	0.996679126
9	0.999986049	0.996264793
10	0.999982783	0.995850633

Table 3-1 presented the expected probability of a successful flight without transponder system failure for a single aircraft. However, the air-carrier population in 1979 consisted of 2,623* aircraft flying a total of 6.94 million hours. The effect of the transponder system reliability on the total population for the entire year provides a better insight into system performance as it affects the ATC system. The probability of at least one

*Data from *FAA Aviation Forecast, Fiscal Years 1980-1991*, dated September 1979, prepared by DOT/FAA Office of Aviation Policy.

system failure can be expressed as a function of the number of flights flown during the year and evaluated by use of the following formula:

$$P_f = 1 - P_s^n \tag{3-3}$$

where

P_f = probability of failure

P_s = probability of success for a single aircraft

n = number of flights per year

However, in order to identify the probability of a number of failures occurring as a function of flight duration for the entire air-carrier population, the following equation, which will result in a binomial distribution of predicted failures, should be used.

$$P_{(x)} = \binom{n}{x} P^x (1 - P)^{n-x}$$

$$= \frac{n!}{x!(n - x)!} P^n (1 - P)^{n-x} \tag{3-4}$$

where

n = number of flights per year

x = number of failures (e.g., 0, 1, 2, 3, ...)

$P = (1 - P_s)$ = probability of failure for a single aircraft

Since n is large and P is small, the Poisson distribution may be used to approximate the binomial distribution by letting $\lambda t = nP$; this will give the probability of exactly x failures in n flights:

$$P_{(x)} \simeq \frac{e^{-nP} (nP)^x}{x!} \tag{3-5}$$

Figure 3-1 presents the results of applying Equation 3-5 as a function of flight duration, assuming that all aircraft had dual transponders and all flights included in the 6.94 million hours were of equal duration. The results are presented graphically as curves to permit identification of the point distribution of failure probability for the five flight scenarios. The highest probability of failure (36 percent chance of one failure) occurs if all flights are of one-hour duration. In order to identify the effect of these results on the operation of the NAS, Equation 3-3 can be applied by letting the probability of at least one failure (P_f) equal 95 percent and solving for n (the number of flights per year necessary to generate this probability).

$$n = \frac{\ln (1 - P_f)}{\ln P_s} = 17,316,370 \text{ flights} \qquad (3\text{-}6)$$

More than eight million flights of one-hour duration would be required in one year to give a 95 percent chance of encountering one or more failures. This is about six times the actual number of flights in a year. The air carriers participating in this study reported that for the period covered by these data they had experienced not one dual failure of transponders.

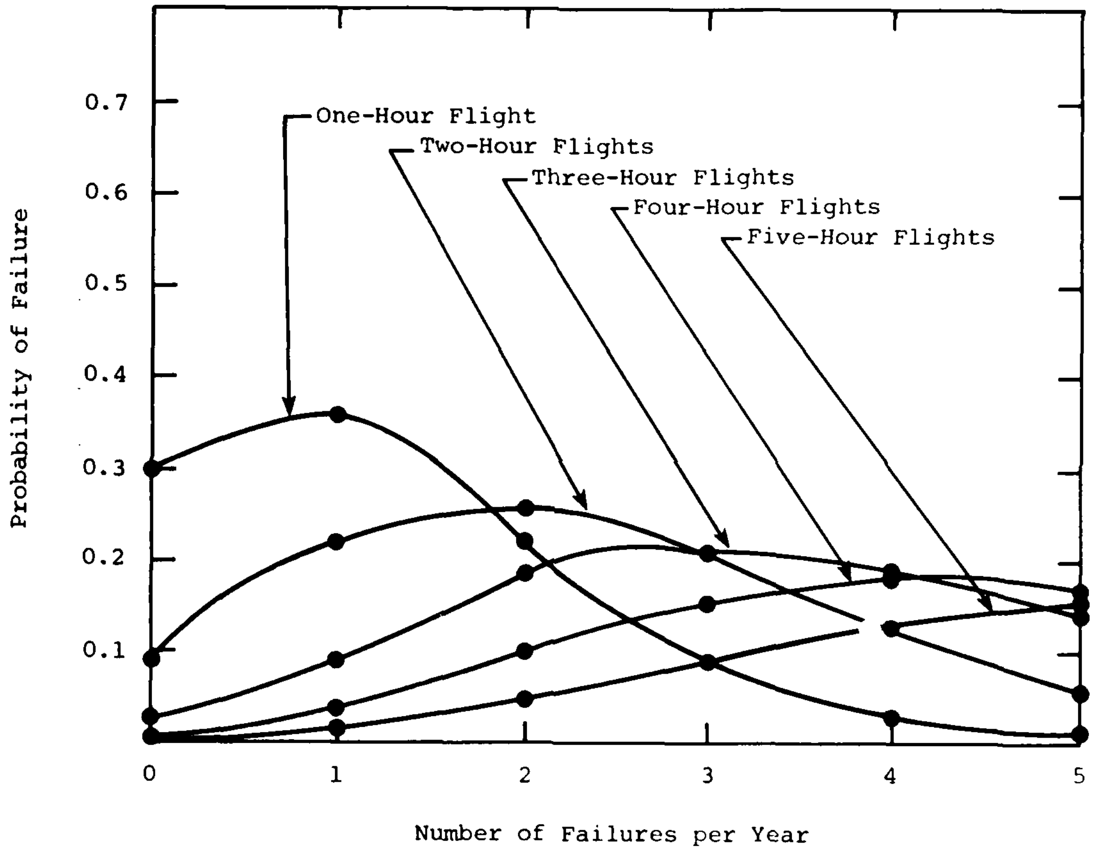


Figure 3-1. PROBABILITY OF FAILURES AS A FUNCTION OF FLIGHT DURATION - AIR CARRIERS

3.2 AVAILABILITY OF TRANSPONDER REPLIES IN LOW-PERFORMANCE GENERAL AVIATION AIRCRAFT POPULATION

The single-engine and light twin-engine general aviation aircraft normally operate in airspace where transponders are not mandatory. However, on the basis of the information presented in Chapter Two it is obvious that the majority of aircraft in this population are equipped with ATC transponders. Although there is no guarantee that every aircraft initiating a flight has

a working transponder, for purposes of this analysis the assumption is made that all transponders are operational at flight inception.

The probability of a successful flight without a transponder failure is presented in Table 3-2 for flights ranging from 1 to 10 hours. Equation 3-2 is applicable since the general aviation aircraft typically have single-transponder systems. The unit failure rate is based on the MTBF of 1,945 hours developed in Chapter Two.

Table 3-2. PROBABILITY OF MISSION SUCCESS AS A FUNCTION OF MISSION DURATION - GENERAL AVIATION COMMUNITY

Duration of Flight (Hours)	Probability of Success - Single System
1	0.999485993
2	0.998972251
3	0.998458773
4	0.997945558
5	0.997432607
6	0.996919920
7	0.996407497
8	0.995895337
9	0.995383440
10	0.994871806

Unlike air-carrier aircraft, which are likely to appear anywhere in the NAS because of the carriers' route structures, the general aviation aircraft considered in this evaluation are primarily used for short trips. Data for 1979 in the FAA Aviation Forecasts report that 178,200 single-engine and multi-engine aircraft flew a total of 33.4 million hours, or 187.4* hours per aircraft per year. In order to evaluate the potential effect of transponder failure on the ATC and considering that each aircraft probably does not leave the area of coverage of one center (ARTCC), the probability of the number of transponder failures that may be seen by a center is calculated by use of Equation 3-5. Figure 3-2 presents the results of the evaluation as a function of flight duration. The area chosen for evaluation is the Los Angeles Center area, covering half of California and part of Nevada. Report No. FAA-MS-79-5 identifies 24,835 active general aviation aircraft in the two states and it is assumed that the LA Center area has half of the population, or 12,418 aircraft. Of this total, 92.7 percent (or 11,508) are single-engine or multi-engine aircraft, based on the national average. These

*These averages are for single-engine and light twin-engine aircraft, rather than for all aircraft considered in Chapter Two.

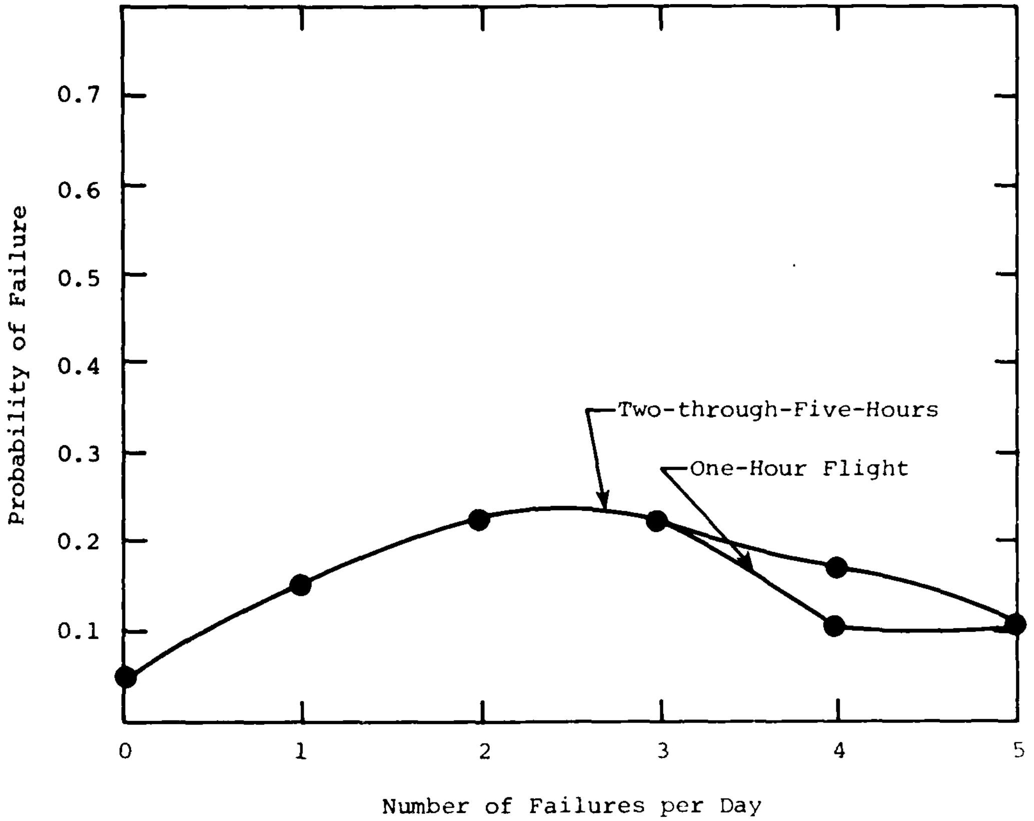


Figure 3-2. PROBABILITY OF FAILURES AS A FUNCTION OF FLIGHT DURATION - GENERAL AVIATION

aircraft account for 2,156,670 flying hours per year, or 5,909 hours per day. Because of the large population involved in the analysis using single-transponder systems, the probability of failure is evaluated on a daily, rather than annual basis. Although the same one to five hours of flight duration was considered as in the case of air-carrier aircraft, the results showed little variability when Equation 3-5 was applied, resulting in the point distribution shown in Figure 3-2. The maximum probability of failure (22 percent probability of either two or three failures) during a typical day of general aviation activity in the Los Angeles Center area is equivalent to a 95 percent confidence of Equation 3-3 of at least one failure per day for a population of 2,913 aircraft operating two-hour flights. Most of the failures, however, will not affect ATC operations because they will occur on aircraft not under control of the centers. All other centers, except Oakland ARTCC, will experience fewer transponder failures daily since the density of general aviation aircraft traffic is lower than in the two California Center areas.

CHAPTER FOUR

CONCLUSIONS OF ANALYSES

The modern air traffic control system is highly dependent on the availability of transponder replies for aircraft identification and positioning to permit the safe and orderly flow of aircraft under ATC control. This study documents the historical experience of transponder reliabilities for commercial air carriers and low-performance general aviation aircraft on the basis of actual 12-month removal rates and manufacturers' warranty actions. The ATC transponder has been in use since the early sixties without a major functional change; it has a mature design and is reliably performing a critical ATC function. Since the majority of aircraft registered in the United States are equipped with transponders, air traffic controllers depend on information provided by the secondary surveillance to monitor flight progress. The controllers in centers responsible for en-route traffic are usually exposed to air-carrier and high-performance general aviation aircraft. The air-carrier aircraft are equipped with dual systems, giving very high system reliability. The high-performance general aviation aircraft were not studied and therefore no conclusion has been reached on the reliability of their transponders. Center controllers are also exposed to the low-performance general aviation aircraft, but only a small percentage of this community is under center control; the majority of the flying activity is below the controlled airways. Terminal area controllers, however, are much more exposed to all traffic within their volume of airspace and are much more concerned with the reliabilities of all transponder-equipped aircraft.

This study has evaluated the reliabilities of the transponders used by air carriers and low-performance general aviation aircraft and attempted to provide a probability of system failure in a specific environment in order to provide a measure of its effect on ATC controllers. In the worst case examined, the results show that for air-carrier operations of aircraft with dual transponders there is a 36 percent probability of exactly one failure per year somewhere in the NAS system. This can be interpreted as a 95 percent probability of at least one failure in 17.3 million one-hour flights per year. Considering that the air carriers recorded almost 7 million flight hours in 1979, the transponder system must be judged as highly reliable. In the case of general aviation aircraft, which are usually equipped with single transponder systems and operate within one center control area, the probability of failure is much greater. In the example evaluated in Chapter Three, the worst case probability of exactly two or exactly three units failing

was 22 percent for a population flying 5,900 hours per day. Although this failure rate may appear high, the data show that if the average flight time of the aircraft is two hours, there is a 95 percent probability that one failure will occur per day among 2,913 aircraft in any volume of airspace.

Table 4-1 summarizes the results of this reliability study for the classes of users evaluated. The air-carrier data are based on equipment removal during the 12 months of operation and result in reliability expressed as mean time between unit removals (MTBUR); the general aviation data are based on warranty actions and result in reliability expressed as mean time between failures (MTBF).

Table 4-1. SUMMARY OF TRANSPONDER RELIABILITY BASED ON A 12-MONTH SAMPLE OF REMOVAL AND WARRANTY DATA - AIR CARRIER AND GENERAL AVIATION TRANSPONDERS

Equipment	Number of Units in Sample (12-month Period)	Number of Removals or Warranty Claims	Unit Failure Rate (per 1,000 Hours)	MTBUR or MTBF
Air Carrier Transponder	2,850	33,133	0.4158	2,405
Air Carrier Control Panel	738	203	0.0844	11,855
General Aviation Transponder	26,053	3,252	0.5141	1,945